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ABSTRACT

This article describes an approach to modifying science students' alternative conceptions of physical phenomena by means of diagnostic and remedial microcomputer programs designed in accord with a model of conceptual change. Current applications of microcomputers are discussed, including numerical work, drill and testing, tutorials, simulation, and real time use. A review of the literature on alternative conceptions focuses on the concepts of speed and force in physics instruction, and a model of conceptual change is outlined which implies that instruction should involve the identification or diagnosis of student conceptions, the lowering of the status or remediation of alternative conceptions, and the raising of the status of the new instructional content. Two specific programs designed to diagnose some alternative conceptions of speed and force are described, as well as the results of using the programs with first year university science students. These results indicate that the programs effected dramatic changes in a common alternative conception of speed and were able to diagnose several interrelated aspects of alternative conceptions of force. Twenty-two references are listed. (Author/LMM)

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Microcomputers, Conceptual Change and the Design of Science Instruction: Examples from Kinematics and Dynamics

Peter W. Hewson

The microcomputer has arrived on the educational scene. The combination of low cost and versatility has meant that its appeal is eclectic — administrators, teachers and students can all justify the modest outlay for a variety of reasons, ranging from the serious to the trivial. There is every reason to expect that within a few short years, the microcomputer will be as ubiquitous in schools as overhead, slide and movie projectors.

But what will be its impact in the long term? Will cost-conscious accountants find that books are able to supply students with the same information at a fraction of the cost, and without the possibility of being diverted into mindless arcade game playing? Or will education take on the magical quality of George Leonard's vision in *Education and Ecstacy*?[1] In my view, this depends on the ingenuity with which we explore the possibilities in the new medium. On the one hand, using the microcomputer to take over the functions that older technologies and techniques have performed satisfactorily will be a self-defeating exercise. On the other hand, finding new functions which could not be performed in the past holds the potential of opening vistas in the future which are unimagined in the present.

In this article, I shall be exploring one possible function for the microcomputer in education. This new function arises from the constructivist view of learning which I recently discussed in this journal;[2] it is a view which explains the now well-documented finding that all students bring to the science classroom surprisingly extensive theories about how the natural world works.[3,4] As Champagne, Klopfer and Gunstone[5] have pointed out, these theories (which they call 'alternative conceptual systems', Driver[6] calls 'alternative frameworks', and which I shall refer to as 'alternative conceptions'[7]) have some interesting characteristics:

- they are often held by students who have had no formal instruction in the subject;
- they are often significantly different from generally accepted views of the subject;
- they are consistent across different groups; and
- they are surprisingly resistant to change as a result of traditional instruction.

More specifically, I shall be considering if a microcomputer can be used to diagnose whether a student holds a specific alternative conception and, if so, to provide remedial instruction based on a model of learning as conceptual change which will assist the student to change his or her views.

In the rest of this article I shall:

- discuss current usage of microcomputers in science instruction;
- review the relevant literature on alternative conceptions, with particular attention to the concepts of speed and force;
- outline a theory of conceptual change which suggests how to design instruction aimed at replacing alternative conceptions;
- describe microcomputer programs designed to diagnose and remediate some alternative conceptions of speed and force;
- outline the results of using these programs with first year university students; and
- summarize the outcomes of the paper.

Microcomputers in science instruction

Microcomputers have a number of considerable advantages over many of the other educational media presently in use.[8] Firstly, students can interact directly with a microcomputer. Thus, provided the software requires it of them, students play a very much more active role in learning than with other media. Secondly, students can get individual attention for their specific difficulties from the microcomputer. Thirdly, microcomputers allow students to control the pace at which they work, so that a student who is having difficulty with one particular section of work can take the time needed to master it before moving on to the next section.

Microcomputers are currently being used in a number of different ways in science instruction at both secondary and tertiary levels,[9] all of which make at least some use of their specific capabilities.

Numerical work

The ability of the microcomputer to perform numerical calculations rapidly and efficiently allows students to investigate the scientific rather than the mathematical aspects of equations by eliminating tedious calculation. For example, introductory physics courses are generally restricted to those problems for which the laws of motion can be solved analytically. This restriction can now be removed, since iterative solution techniques are easy to implement on a computer.

Drill and testing

The capability of storing many questions in a data bank, of varying the type and content of questions asked, of asking many different questions in a relatively short period of time, of recording and evaluating student responses, of being able to give feedback based on the student's response and of being readily available, makes drill and testing obvious functions of a microcomputer in science instruction

Tutorial

The microcomputer cannot compete with a book purely in the presentation of information. When its interactive capability is, however, combined with the presentation of information, programs with carefully designed questions and branches which allow a student to take different paths through the material, can involve him or her far more actively in learning than a book can. This advantage is particularly enhanced when dynamic graphics are used.

Simulation

All too frequently, real world experiences are difficult to repeat in the laboratory, are too complicated for introductory students to analyse, happen too rapidly to be seen, can only be observed using complicated instrumentation which obscures the desired phenomena, or are otherwise unexaminable. The ability of the microcomputer to simulate this type of phenomenon allows the student to expand his or her range of experiences greatly.

Real time use

Scientists have interfaced computers with their experimental apparatus for years. Thompson, however, points out that this capability can bring experiments which are normally unavailable into the student laboratory

As Bork points out, the microcomputer's capability of individual response means that

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it can play the role of a Socratic tutor, by leading the student through a series of carefully structured questions which are responsive to his or her answers.

These are exciting possibilities but as Bork indicates, they represent the state of the art, rather than a final definitive list. There are likely to be far-reaching consequences for courses, curricula and institutions as a result of current and future developments in both computer hardware and software. There is much to be learned about how people learn and about how to incorporate this into the design of instructional software.

Alternative conceptions

As I have outlined elsewhere,[10] the occurrence of alternative conceptions is consistent with two other ideas which are of particular importance in science education today. Firstly, people strive to make sense of their experience. Secondly, people use the knowledge they possess in their attempts to make sense of their experience. Thus, as a direct result of the above two ideas, individuals from different backgrounds, having different experiences and knowing different things, are likely to construct alternative conceptions from the same information.

The significance of alternative conceptions depends, among other things, on the large number of different alternatives in different content areas which have been identified to date, the considerable number of students who hold them, and, more tentatively, the suggestion that environmental, linguistic and cultural factors play a part in their occurrence. Researchers from various countries have documented alternative conceptions in topics as diverse as vectors, kinematics, dynamics (including friction, gravity, energy, momentum and pressure), heat and temperature, electricity, light, density (including mass and volume), the particulate theory of matter, the earth as a cosmic body, evolution, heredity, the circulatory system and life. For example, dynamics and kinematics have been reviewed by McDermott,[11] and heat, temperature, light and electricity by Tiberghien.[12] A more extensive, but less detailed, review has been provided by Driver and Erickson.[13]

At a recent international seminar on 'Misconceptions in Science and Mathematics', more than 50 papers were presented on topics in physics, chemistry, biology and mathematics.[3] The interest engendered by the seminar, which attracted participants from many countries, and the extent of the list given above are just two indications that alternative conceptions are a factor which can no longer be ignored in science education today.

An alternative conception of speed

The alternative conception of speed considered in this article was first identified by Trowbridge and McDermott[14] in the course of a systematic study of the ways in which students think about motion. By using apparatus which allowed them to demonstrate the same motion repeatedly, they assessed understanding of students' conceptions of speed by the degree to which a student successfully applied this conception to the interpretation of these simple motions of real objects. More specifically, they found that, before instruction, at least 30% of all students enrolled in a wide variety of introductory physics courses at the University of Washington were unable to compare the speeds of two objects satisfactorily. In general, these students used a 'position' criterion for determining when two objects were moving at the same speed. In other words, when two objects were next to one another (i.e. at the same position), the students said that they were moving at the same speed. Conversely, they also concluded that when two objects maintained a constant separation, they were not moving at the same speed. A possible reason for the plausibility of this conception arises from the fact that sometimes, such as when two cars travel next to one another on the freeway, the position criterion will give the right answer. In other cases, such as when one car overtakes a second, it does not. One of the microcomputer programs described below was designed to address this alternative conception of speed.

Alternative conceptions of force

Research into alternative conceptions of force has shown that they form a complex of interlocking ideas which are far more extended and pervasive than is the case with the alternative conception of speed considered above. For example, Watts[15] outlined eight distinctive alternative conceptions of force. In order to keep the number of programs to manageable proportions in the first instance, it was necessary to consider only those alternatives which were most prevalent and therefore most likely to cause difficulty in first year physics.

The major alternative conception which was considered is centred on the concept of force in the context of a consideration of motion and its causes. The essence of this conception is that a force is necessary whenever motion is present. Viennot[16] found that a student holding this conception would use the velocity of an object, rather than its acceleration, to deduce the presence of forces. Her results indicated that the use of this conception was dependent on the context of the question which was asked. If the total motion of the object was given, its use was far more prevalent than if students were given an equation of motion and asked to calculate the force. She called this the 'supply of force' notion, i.e. 'the force in a body which keeps it moving'. Clement[17] summarized the same idea as 'motion implies a force', noted that this 'force' was more likely to be used when there was an obvious opposing force, and that students thought it would 'die out' or 'build up' in order to account for changes in speed. Watts drew a distinction between a conception in which the motion itself is the force, typically expressed as 'the force of the moving object'; and one in which the force is external to the moving object, but without being identified with any other object. He has paraphrased this latter notion as follows: 'If a body is moving there is a force acting upon it in the direction of the movement. If a body is not moving there is no force acting upon it.'

Another aspect of the alternative conception of 'motion implies a force', about which Viennot, Clement and Watts have all agreed, is the frequent lack of a distinction between force and energy. For example, Viennot commented that energy in many situations 'is inextricably mixed with the concept of force in a single undifferentiated complex', and Watts claimed that for some students force is energy.

Motion is of interest because many students regard it as a force, but in the Newtonian sense it is not. In contrast, the reverse is the case with two other concepts — gravity and friction. Many students do not regard them as forces, although in the Newtonian sense they are. Although there has been some research into this question,[18-20] the reasons for this are speculative. It seems, however, that some students tend to think of forces as associated with active agents such as people or machines.[21] The corollary to this is that they find it hard to conceive of passive agents exerting a force, such as a table exerting a force on the book which it is supporting. Gravity and friction are likewise not regarded as forces because they are due to passive agents. This is most clearly shown by students who feel there is no need to provide any explanation of why objects fall to the ground, or why moving objects slow down as they move across a surface — they regard them as natural occurrences.

A model of conceptual change

In this study the question of how a microcomputer can make explicit use of an identified alternative conception in remedial instruction was addressed by thinking of learning as a change in a student's conception. From this point of view, learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction. If these conceptions can be reconciled, learning proceeds without problem. If, however, they cannot be reconciled, then learning requires that existing conceptions be restructured or even exchanged for the new. The recognition that change of this nature may have to occur forms the basis of the model of learning as conceptual change which we have developed.[10,22]

The model of conceptual change outlines the conditions which a new conception has to satisfy before it can be integrated with existing knowledge. Three questions must be asked of each conception:

- Is it intelligible (*I*)? Does the person know what it means? Can he or she construct a coherent representation of it and see that it is internally consistent, without necessarily believing it to be true?
- Is it plausible (*P*)? In addition to being intelligible, is it also true? Is it reconcilable with other existing conceptions? Is it how the world really is?
- Is it fruitful (*F*)? In addition to being plausible, is it useful? Does it clear up anomalous results? Does it suggest further experiments or new approaches?

The answers to these three questions are used to determine the status of a question — no status if all three answers are negative; status *I* if the first answer is positive; status *IP* if the first two answers are positive; and status *IPF* if all three answers are positive. Because conceptual change can occur only when status changes, the next question to consider is: how does status change? It does not change spontaneously. It is lowered only if there is cause for dissatisfaction, and it rises only if sources of dissatisfaction are removed and some advantage is gained. In other words, the success of a microcomputer program designed to effect conceptual change depends, in part, on the extent to which it is able to make a student dissatisfied with the conceptions which he or she holds.

Effecting conceptual change with

The implications of the conceptual change model for addressing alternative conceptions are straightforward. These are:

1) Diagnosis. It is necessary to know whether or not any given student holds the alternative conception under consideration. This can be determined only by using a diagnostic test.

2) Remediation — the lowering of status. The model indicates that it is reasonable to assume that a student holding a conception does so because its status is at least *IP*. If, however, this conception is irreconcilable with a new conception which is to be taught, then it is impossible for the status of the new conception to rise to *IP* until the status of the existing conception falls. In other words, it is necessary to address the old conception with the explicit intention of creating dissatisfaction with it, thereby lowering its status.

3) Remediation — the raising of status. Teachers have always put considerable effort into explaining new ideas. In terms of the model, this will always be necessary in order to make a new idea intelligible to the student. In addition, however, the model suggests that it is necessary to show that the new conception is a better option than the old, because it does what the old could not do and more. In other words, it is necessary to raise the status of the new to *IPF*, or at least *IP*.

The ability of the microcomputer to allow a student to interact actively with instructional material and to follow an individualized path at his or her own pace is very useful in designing instruction to achieve the three stages outlined above. For example, the results of the diagnostic test will show whether the student holds an alternative conception whose status needs to be lowered. On this basis, the student can be directed to specific remedial programs which can be worked through as and when required. In addition, the ability of the microcomputer to simulate motion is particularly useful in the work described in this article, because of the central role which motion plays in the alternative conceptions of speed and force which I outlined above.

A microcomputer program on speed

The program was designed to diagnose students who used a position criterion for comparing relative motion, and to provide remedial sequences whose aim was to persuade these students to change to an acceptable criterion. It is clear that this is a relatively unimportant alternative conception which is simple to identify and relatively isolated from other alternatives, and which many students correct for themselves. It was, however, chosen for the following reasons. Firstly, the position criterion seems to be the only plausible alternative. Trowbridge and McDermott[14] comment that 'virtually every failure to make a proper comparison can be attributed to use of the position criterion to determine relative velocity'. This makes the remedial task significantly easier. Secondly, if we are able to diagnose and remedy a simple example such as this using a microcomputer, it ought to provide us with guidelines for tackling alternatives which are more significant and more complex.

Diagnosis

The diagnostic stage consists of six different races in each of which two 'cars' move from left to right across the screen. The student records a response by pressing a control button in accord with the instruction: 'Press the button when you think the two cars are moving at the same speed.'

The races, which include the two used by Trowbridge and McDermott, were designed on the basis of their ability to distinguish between the correct and position criteria. In other words, there are no occasions where both cars are moving side by side at the same speed. In addition, other factors such as acceleration and deceleration, which affect the perceptual appearance of the races without changing the essential components of the task, are varied. The use of six races is necessary to allow for possible mistakes and to provide a greater assurance that the diagnosis made is the correct one.

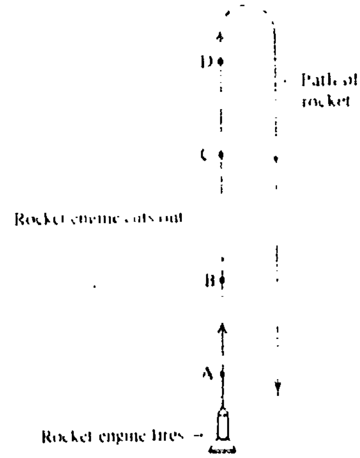

Fig. 1. Summary of task set by first diagnostic program (DG 1): What forces (names, directions, comparative magnitudes) are acting on the rocket at points *A*, *B*, *C* and *D*?

Remediation

In the program the two aspects of the remedial stage are combined in two further races which were designed to lower the status of the position criterion while at the same time introducing the correct criterion. This was done by considering two extreme cases which introduce perceptual anomalies for a student using the position criterion. In the first case, one car remains in the centre of the screen, clearly not moving; while the other travels past it at a constant speed, equally obviously in motion. The race clearly pinpoints the anomaly by showing one car moving and the other stationary while at the same point. In the second case, both cars travel at the same constant speed across the screen, with the distance between them remaining constant, i.e. they do not pass one another. This race shows that two cars do not have to be at the same place while moving with the same speed, and at the same time introduces the correct criterion of the constant inter-car distance.

Results of program use

It is possible for a student in one session of 20 minutes to work through the diagnosis part of the program and, if necessary, to do the remedial work and repeat the diagnosis. It is easy, therefore, to gather data on the effect of the program itself, as opposed to other possible influences on student responses. The responses obtained from 85 students in a first year physics course at this university [Physics I(J1)] are representative of the results which the program can achieve. A total of 23 students could not judge speeds correctly. Of these, 14 worked

Table 1. Correct (C), 'position' (P) and random (X) scores of 7 Physics I(JI) students in February 1983.

Student	CPX score Before	CPX score After	Change in scores ΔC	ΔP	ΔX
A	060	403	+4	−6	+3
B	431	502	+1	−3	+1
C	204	222	0	+2	−2
D	251	433	+2	−2	+2
E	241	500	+3	−4	−1
F	240	600	+4	−4	0
G	214	501	+3	−1	−3

through the remedial part and repeated the diagnosis, and 10 out of 14 changed and were able to judge speeds correctly. Even without a full-scale evaluation, it is possible to see that the program is doing very satisfactorily what it was designed to do.

It is necessary in interpreting the results of students who did not respond correctly to note that the data is gathered in the form of correct (C), position (P) and random (X) responses to the six diagnostic races. Because it is possible to make more than one type of response to a given race, the total number of responses may be more than six. The C, P and X scores of a representative group of these students before and after doing the remedial program are shown in Table 1, together with the changes in these scores.

It is clear that there was a substantial increase in the number of C scores, and a corresponding decrease in P scores, with some of the individual changes being particularly striking. The significance of these changes is strengthened by considering that students were not shown which were the correct points in the diagnostic races, but were simply shown the procedure which they had to apply for themselves. In addition the same students were asked a few weeks later about their responses. Those whose responses had not changed immediately after the program were still confused. One response here was that cars would move at the same speed 'when their speeds remain constant, and when they travelled together (side by side)'. Conversely, those who had changed, acknowledged their change, and could explain how they now judged equal speeds. For example, one student said he 'made a mistake the first time by taking the point where they pass each other as the same speed' and would now look for 'when they keep more or less the same distance apart'.

Microcomputer programs on force

The programs were designed for students who believe that moving objects always require forces to keep them moving, who confuse force with related concepts such as energy and momentum, and who think that forces are due to active agents and are therefore uncertain about gravity and friction. In order to address these ideas, it is necessary to be able to discuss a prototypical force about which there is likely to be general agreement. The most common prototypes are probably human pushes or pulls, but they suffer from the problem that they are generally variable in magnitude and of short duration. The force exerted by a rocket, however, is clearly an active force, and it is easy to imagine how to control the magnitude, the direction and the duration of the force. As a result the rocket is a constant theme throughout the programs.

Diagnosis

The diagnostic programs were adapted from a task used by Clement,[17] in which he asked students to consider the forces which acted on a coin that was thrown vertically upwards. More specifically, he asked them to name the forces, to show their directions and to compare their magnitudes after the coin had left the hand, and while it was still moving upwards. Clement found that this task evoked the response that there was an upward force from 70% of a group of engineering students who had completed a first course of university physics. On a similar task, 33% of the first year physics major students at this university gave the same response after completing the section on mechanics. In other words, it is a good task for identifying students who hold the alternative conception that 'motion implies a force'.

The first diagnostic task (DG 1) simulates the motion of a rocket which takes off vertically upwards. After a short while, the engine cuts out and the rocket continues to

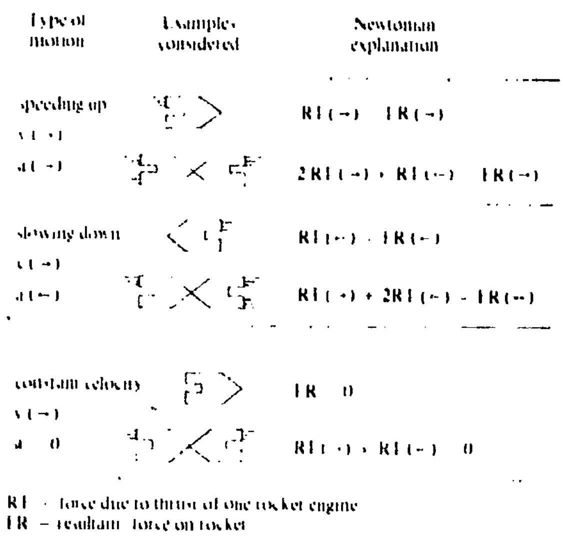

Fig. 2. The Newtonian explanation of three types of motion considered in first remedial program (RM 1). All rockets move from left to right. Arrows in brackets show directions only, and not magnitudes.

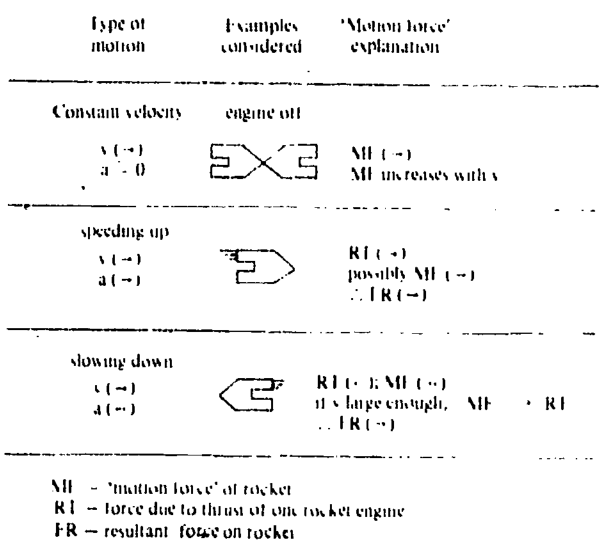

Fig. 3. The 'motion force' explanation of three types of motion considered in second remedial program (RM 2). All rockets move from left to right. Arrows in brackets show directions only, and not magnitudes.

move upwards but now slows down until it stops, before falling back to earth. Students are asked to consider the forces acting on the rocket at four points — after take-off, before and after engine cut-out, and before the rocket stops moving upwards. At each point they are asked to name the forces acting, give their directions and compare their magnitudes. In addition they are asked whether the same forces are acting at successive points, and if so, how their magnitudes compare. The task is summarized in Fig. 1.

This task was designed to answer the following questions: What types of quantities are regarded as forces? In particular, does the student regard gravity and motion as forces? With respect to magnitudes, is the largest force necessarily in the direction of motion?

The second diagnostic task (DG 2) simulates the motion of a rocket travelling horizontally on a track which can be either rough or smooth, i.e. frictionless. The rocket starts from rest, speeds up until the engine cuts out, and then either slows down (Part I) or continues moving at a constant speed (Part II), depending on whether or not the track is smooth. In a further option on the smooth surface, the engine does not cut out, but instead reverses its direction so that the rocket slows down, stops, and moves off in the opposite direction. As before, the students are asked to name the forces, give their directions and compare their magnitudes at different points while the engine is on and after cut-out or direction reversal. This task was designed to gather the additional information of whether students regarded friction as a force and how they related forces to a constant velocity motion.

Remediation

The remedial programs use Viennot's result that the force conception which a student uses depends on the context in which the task is set. In other words, there are examples where there is general agreement that a prototypical force is acting. The overall aim of the remedial programs is to establish what effect such a prototypical force, or combination of such forces, has on the motion of an object. Once these effects are established, the argument is turned around and they are used to determine what forces might be acting on an object whose motion is given. Included in these motions are those which give rise to the alternative conceptions discussed above, so that the conflicting explanations can be compared.

The first remedial program (RM 1) was designed to establish the effect that prototypical forces have on the motion of an object on which they act. For the reasons discussed above, rocket engines were used to exert prototypical forces, and for simplicity motion was restricted to one dimension. By using combinations of simple constant-thrust rockets which can be either on or off, or act to the left or the right, different resultant forces can be obtained. Within these constraints, the effects of forces can be determined in qualitative terms, i.e. a force acting on its own, or the resultant of a number of forces, is able to accelerate (speed up) an object which is either at rest or already moving; and is able to decelerate (slow down), stop and change the direction of a moving object. As important as these effects is the converse: when no force or a zero resultant force acts on a moving object, the object continues to move with an unchanging velocity. These results are summarized in Fig. 2.

The second remedial program (RM 2) was designed to address the alternative conception of 'motion implies a force'. Some characteristics of such a 'motion force' are first established using an example particularly likely to evoke this conception: an object moving with constant velocity without any obvious force in the direction of motion. In particular, the idea is established that if the 'motion force' exists, it is reasonable to expect it to increase with the speed of the object. After considering the uncontroversial example of an object which is speeding up, the crucial example is presented. An object is shown to be slowing down under the action of a rocket firing in the reverse direction to that of the 'motion force'. The direction of the resultant of rocket force and motion force depends on their relative magnitudes, and since by considering an object which is moving fast enough, it is always possible to have a motion force larger than the rocket force, there must be a case where the 'resultant' is in the direction of motion, while the object is slowing down. These results, based on the same three examples used in RM 1, are summarized in Fig. 3.

The last result, however, contradicts what happens when only prototypical forces act; i.e. it is designed to lower the status of the 'motion force' conception. The process is carried on by showing that a 'motion force' on its own is unable to have the same effect as a prototypical force; i.e. to change velocity, and finally the fact that a moving object is different from a stationary object is recognized by differentiating the force itself from the motion produced, and calling the latter momentum rather than motion force.

The third remedial program (RM 3) was designed to address the alternative conception that passive agents, such as gravity and friction, were not forces. By using similar examples, and allowing the student to experiment with motions in which gravity and friction could be switched on or off at will, he or she was shown that these two could be regarded as forces, because they were able to produce the same effects that prototypical forces did.

Results of program use

The responses made by students who have used these programs have provided answers to many of the questions posed above. These answers are, however, tentative and at this stage specific to Physics I(J1) because trial versions of the programs were used, and they need to be revised. In addition, the second diagnostic program (DG 2) was available only well after the mechanics section of the course had been taught. Thus, because a considerable amount of time intervened between the use of different programs, it is impossible to attribute any specific effect to them.

What types of quantities do Physics I(J1) students regard as forces? This can be determined from the diagnostic programs which require students to type in the names of forces acting. Within the context of the rocket tasks, the responses to DG 1 in February 1983 show five main types of force, only three of these being Newtonian. These three were gravitational force, frictional forces (e.g. 'friction', 'air resistance', 'drag') and rocket thrust (e.g. 'propulsion', 'engine'). Both of the other types were closely related to Viennot's 'supply of force' and Clement's 'motion implies a force' notion. On the one hand was the idea that the property which the rocket had because of its motion was a force. 'Motion', 'momentum', 'inertia', 'inner force', 'kinetic energy' were examples in this category. On the other hand, terms were used which were more descriptive of the motion; e.g. 'speed', 'terminal', 'acceleration', 'upward'. In August 1983, the same categories of response were made to DG 2, although as is shown later, the frequency of the non-Newtonian categories was much lower. These changes are consistent with responses to a question asked in DG 2, 'Are there quantities other than forces which affect the motion of a rocket?' A significant number of students listed 'momentum' or 'inertia'.

A number of more specific questions, all of which require yes/no answers, are given in Table 2. The number of students whose responses enabled an answer to be given is listed, together with the percentage of the group who gave a 'yes' answer.

The responses to questions 1 and 2 show that Physics I(J1) students have little difficulty in identifying the 'passive' quantities of gravity and friction as forces. This confirms the pattern of responses to the more general question discussed above.

Question 3: Is motion a force? This idea is much more prevalent, with more than 60% of the class concurring at the start of the year. As the year progressed, with students working through the remedial programs and attending course lectures on the topic, this percentage dropped significantly to 30%. While this is still not satisfactory, the fact that the responses were made to a range of

Table 2. Student responses to various questions on dynamics; in percentage of available group agreeing and disagreeing with question.

Question	Yes (%)	No (%)	Group size	Source	Date
1. Is gravity a force?	88	12	127	DG 1	2/83
2. Is friction a force?	95	5	79	DG 2(I)	8/83
3. Is motion a force?					
(i) $v\uparrow; a\uparrow$.	63	37	76	DG 1	2/83
(ii) $v\rightarrow; a\uparrow$.	39	61	122	Class test	3/83
(iii) $v\rightarrow; a\leftarrow$.	24	76	70	DG 2(I)	8/83
(iv) $v\rightarrow; a = 0$.	27	73	75	DG 2(II)	8/83
4. Does thrust increase with speed					
(i) when gravity opposes motion?	54	46	76	DG 1	2/83
(ii) when friction opposes motion?	68	32	66	DG 2(I)	8/83
(iii) when no force opposes motion?	53	47	73	DG 2(II)	8/83
5. Is larger force in dirn. of motion?					
(i) $v\uparrow; a\uparrow$.	82	18	28	DG 1	2/83
(ii) $v\rightarrow; a\leftarrow$.	43	57	21	DG 2(I)	8/83

different tasks, both pencil-and-paper and computer-based, suggests that a genuine change has occurred. This, however, needs to be considered in relation to the next question.

Question 4: Does rocket thrust increase with speed? This is a clear expectation of the 'motion implies a force' view, whereas it is not a crucial question for Newtonian mechanics in which increasing, constant and decreasing rocket forces can all produce a speed increase. The diagnostic programs clearly stated, however, that the rocket exerted a constant thrust, so the fact that more than 50% of the available groups of Physics I(J1) students consistently responded affirmatively to the question indicates that the lower percentage of students who state that motion is a force must be regarded circumspectly. Of relevance are the following points. Firstly, question 3 was addressed explicitly in remedial programs whereas Question 4 was not. Secondly, the context-dependency of students' answers is shown by the larger percentage who thought that rocket thrust increased with speed when friction was present. Finally, 8 out of 10 students who changed their responses when friction was present did not think that motion was a force. In other words, the relationship between responses to Questions 3 and 4 is not obvious and needs further consideration.

Question 5: Is the larger force in the direction of motion? Reponses to this question could be given only by students who had already shown that they required a 'force' in the direction of motion. Amongst this group, there was a substantial drop in affirmative answers. This may be a response to the second remedial program (RM 2), which was designed to identify the contradiction inherent in the 'motion force' being the largest on a rocket which is slowing down. This, therefore, is also a result which requires more investigation.

Summary

In this article, I have described the use of microcomputers in addressing students' alternative conceptions of physical phenomena by means of diagnostic and remedial programs. The programs have been designed in accord with a model of conceptual change which implies that instruction should involve the identification or diagnosis of students' conceptions and the lowering of the status or remediation of these conceptions where they are alternative to what is to be taught, in addition to the raising of the status of the new content being taught.

The programs were designed to diagnose and remediate alternative conceptions of speed and force. With respect to speed the results show that this alternative conception is held by many students at first year university level, and that the remedial program is able to effect dramatic changes to this alternative conception. With respect to force, the results show that the programs were able to diagnose a number of interrelated aspects of alternative conceptions of force. Although there is some evidence that student conceptions changed during the course of the year, it is not yet possible to attribute this to the remedial programs, both because of their preliminary nature and because of the complexity of the notion of force in relation to the wide range of situations in which it is applicable. In conclusion, I believe that the research reported in this article is important because it provides a valuable addition to the current range of instructional applications of microcomputers, and it demonstrates the value of the conceptual change model of learning in the design of computer-aided instruction.

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